



Search for $H \rightarrow WW \rightarrow \ell\nu\ell\nu$

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ADM Meeting, 07/29/2005



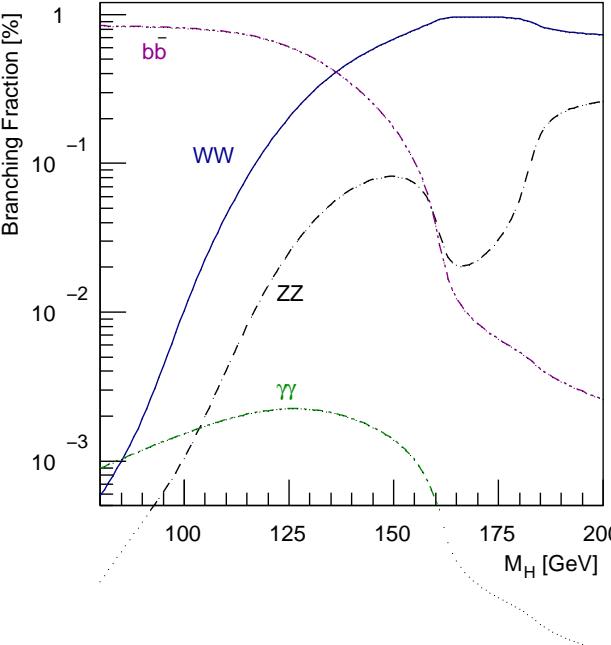
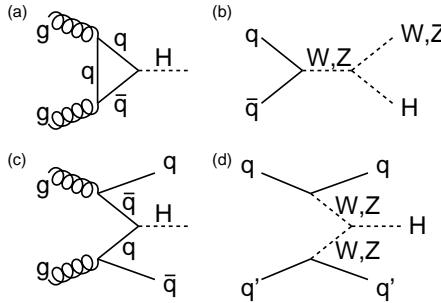
Outline



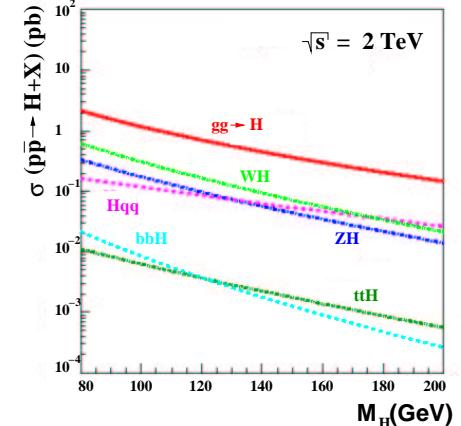
- Introduction
- Data and Monte Carlo samples
- Object selection
- QCD background
- Selection criteria
- Signal efficiencies
- Summary and outlook



Higgs production and decay



- Higgs production in the Standard Model
 - ▲ Four different production processes
 - ▲ Only gluon fusion and Higgs–strahlung relevant at Tevatron
 - ▲ Gluon fusion dominant
 - ▲ Production cross section 0.1–2 pb



- Higgs decay
 - ▲ $M_H < 130$ GeV:
⇒ Higgs decays mostly into $b\bar{b}$
branching fraction 70–90% for $M_H < 125$ GeV
 - ▲ $M_H > 140$ GeV:
⇒ Higgs decay into WW dominant
branching fraction > 90% for $M_H \sim 160$ GeV

Monte Carlo



- Signal

- ▲ Monte Carlo for six Higgs masses between 100 and 200 GeV

M_H(GeV)	100	120	140	160	180	200
$\sigma \times BR$ (pb) SM	0.011	0.089	0.207	0.256	0.181	0.101
4^{th} Gen	0.066	0.471	1.217	2.017	1.471	0.804

- Background

- ▲ Vector boson pair production

- ▶ WW, WZ, ZZ

- ▲ Vector boson production

- ▶ Drell–Yan: $Z/\gamma^* \rightarrow ee$, $Z/\gamma^* \rightarrow \mu\mu$, $Z/\gamma^* \rightarrow \tau\tau$

- ▶ $W(\rightarrow e, \mu) + \text{Jets}$, $W(\rightarrow e, \mu) + \gamma$

- ▲ Other backgrounds

- ▶ $t\bar{t}$, multi-jet production (from data), $\Upsilon \rightarrow ee$, $\Upsilon \rightarrow \mu\mu$

- Monte Carlo with all lepton flavors including τ 's



Monte Carlo corrections



- Standard corrections
 - ▲ Lepton ID corrections
 - ▲ Trigger efficiency
 - ▲ Electron momentum smearing
 - ▲ Muon momentum smearing
- Non standard corrections
 - ▲ p_T reweighting for Z/γ events
 - ▶ Compensates underestimation of jet multiplicities
 - ▲ Reweighting for $W+\gamma$ events
 - ▶ Correction for underestimation of γ conversions





- All data from 2EM, EMMU, and 2MU common skims
 - ▲ Data from April 2002 up to June 2004
 - ▲ All data until the end of triggerlist v12
 - ▲ Pass 1 data and dØcorrect v6
 - ▲ Run selection
 - ▶ Removed runs with hardware failures (Run Quality Database)
 - ▶ Removed bad luminosity blocks (Jet/MET LBN and cal_event_qual)
 - ▲ Removed all double events
- Integrated luminosities
 - ▲ e^+e^- channel: $\int \mathcal{L} dt = 325 \text{ pb}^{-1}$
 - ▲ $e^\pm\mu^\mp$ channel: $\int \mathcal{L} dt = 318 \text{ pb}^{-1}$
 - ▲ $\mu^+\mu^-$ channel: $\int \mathcal{L} dt = 299 \text{ pb}^{-1}$



Object selection (1)



- Electrons
 - ▲ ID = 10, ± 11
 - ▲ Isolation < 0.15
 - ▲ Emfraction > 0.9
 - ▲ HMatrix < 50
 - ▲ Electron Likelihood > 0.3
 - ▲ $| \eta_{det} | < 3.0$
- Muons
 - ▲ Loose muon
 - ▲ Matched to central track
 - ▲ Track isolation: $\sum p_T(\text{Tracks}) < 4 \text{ GeV}$
 - ▲ Timing cut to reject cosmics
 - ▲ Constraint to primary vertex (dca and z)
 - ▲ Recalculate muon p_T with vertex constraint for CFT only tracks
 - ▲ $| \eta_{det} | < 2.0$



Object selection (2)



- Jets
 - ▲ $0.05 < \text{EMFraction} < 0.95$
 - ▲ Coarse hadronic fraction (CHF) < 0.4
 - ▲ Hot fraction < 10
 - ▲ $n_{90} > 1$
 - ▲ $I1\text{set} / (p_T^{Jet} \cdot (1 - \text{CHF})) > 0.4$ (in CC, EC) or > 0.2 (ICD)
 - ▲ Corrected transverse momentum $p_T^{Jet} > 15 \text{ GeV}$
- Missing transverse energy
 - ▲ METB
 - ▲ Corrected with electromagnetic and jet energy scale
 - ▲ Corrected for muons

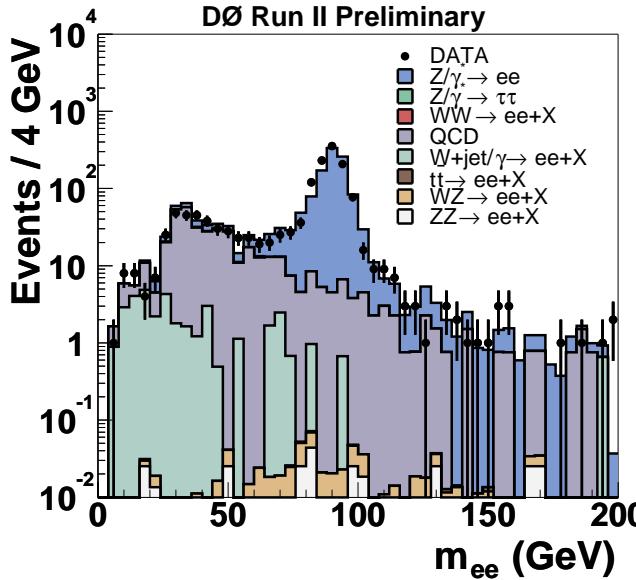


QCD background

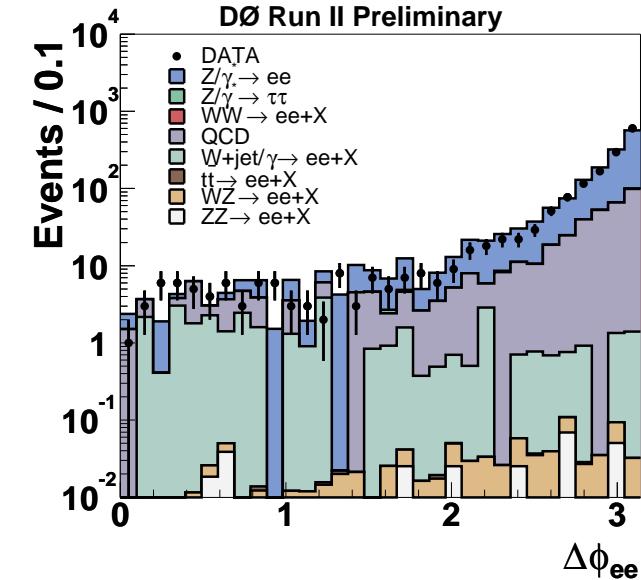


- Define two samples
 - ▲ Search sample: HMatrix < 50 and Likelihood > 0.3 for electrons
 - ▲ Fake sample: HMatrix > 50 and $(e^\pm \mu^\mp)/\text{Lhood} < 0.3$ for electron
Calorimeter isolation > 2.5 GeV for muon
- Use likesign sample to normalize QCD background
 - ▲ Difference between charge misidentification rate in data and Monte Carlo is taken into account
- Normalization factor

$$f_{Norm}^{QCD} = \frac{N_{Sig}^{\pm\pm} - N_{MC}^{\pm\pm}}{N_{Bg}^{\pm\pm}} = \frac{N_{QCD}^{\pm\pm}}{N_{Bg}^{\pm\pm}}$$



$\Leftarrow m_{ee}$ distribution for
likesign events



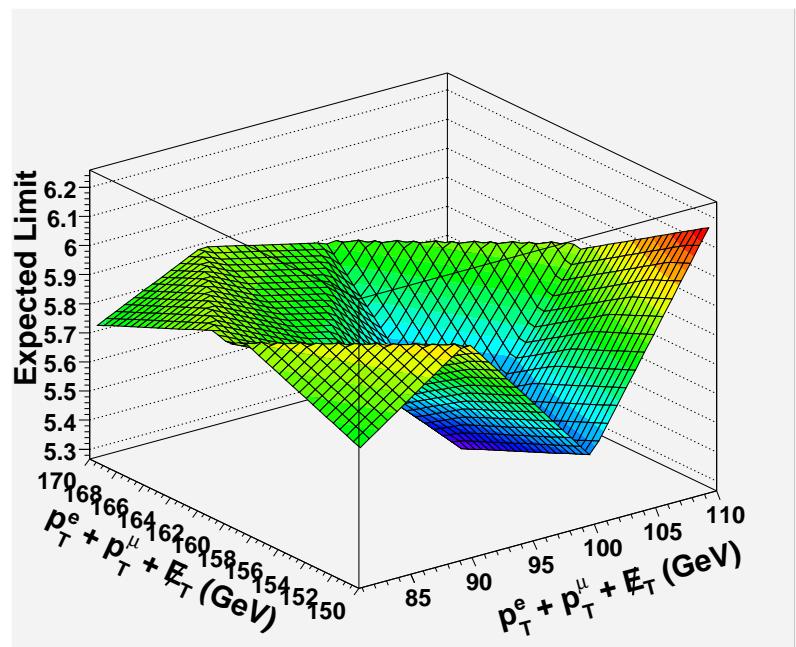
$\Delta\phi_{ee}$ distribution for
likesign events ⇒

Selection

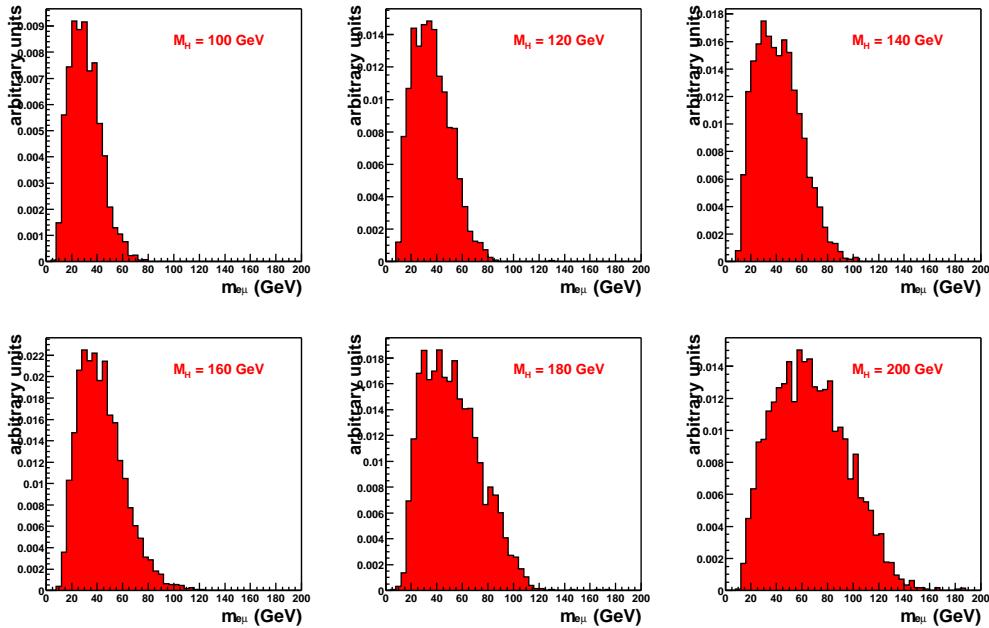


- Use (more or less) same selection for all three final states
 - ▲ Some variations in the $\mu^+ \mu^-$ channel because of worse muon resolution
- Selection optimized for $e^\pm \mu^\mp$ final state
 - ▲ Best sensitivity expected for $e^\pm \mu^\mp$ channel
 - ▲ Five dimensional scan performed to get best expected limit
 - ▶ E_T , E_T^{Sc} , $m_{\ell\ell}$, $m_T^{\ell_1}$, $p_T^{\ell_1} + p_T^{\ell_2} + E_T$
- Some of the selection criteria are Higgs mass dependent
 - ▲ Better limits for different Higgs masses

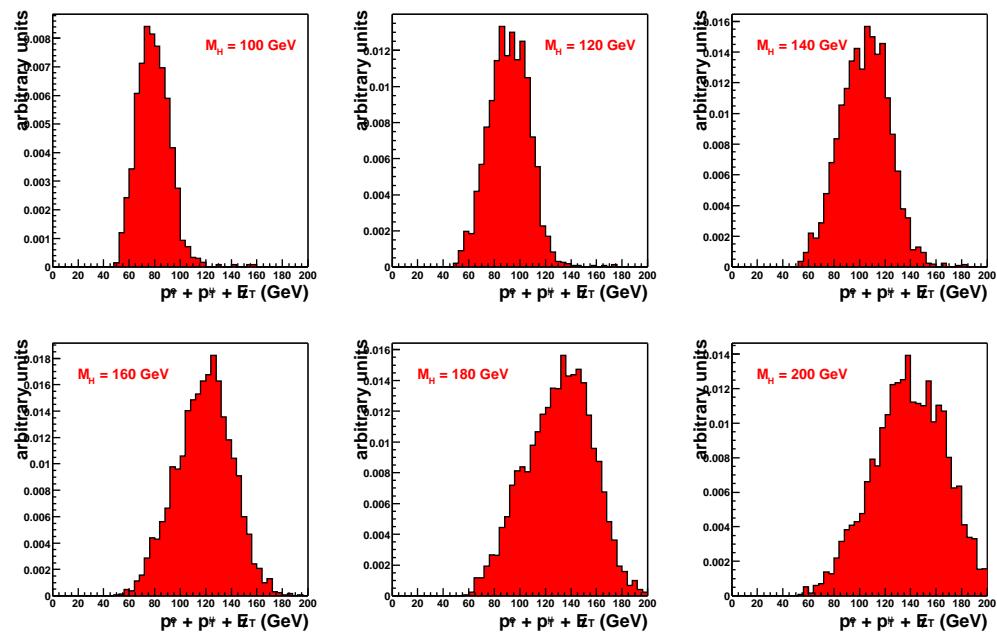
Exp. limit as function of cut variable
 $p_T^{\ell_1} + p_T^{\ell_2} + E_T$



Higgs mass dependent selection



← Invariant dilepton mass



Sum of transverse momenta and E_T ⇒

- Higgs mass dependent selection criteria
 - ▲ Invariant dilepton mass: $m_{\ell\ell} < M_H/2$
 - ▲ Sum of p_T and E_T : $M_H/2 + 20 \text{ GeV} < p_T^{\ell_1} + p_T^{\ell_2} + E_T < M_H$
 - ▲ Transverse dilepton mass: $M_H/2 < m_T^{\ell\ell} < M_H - 10 \text{ GeV}$



Selection criteria

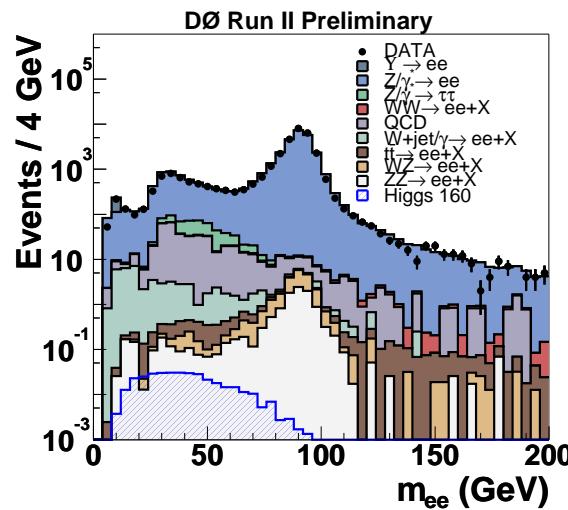


Selection criterion	Value
Cut 1 Preselection	Trigger, ID, leptons with opposite charge and $p_T^{\ell_1} > 15 \text{ GeV}$ and $p_T^{\ell_2} > 10 \text{ GeV}$ ($m_{\mu\mu} > 20 \text{ GeV}$)
Cut 2 Missing transverse energy \cancel{E}_T	$\cancel{E}_T > 20 \text{ GeV}$
Cut 3 Scaled \cancel{E}_T^{Sc}	$\cancel{E}_T^{Sc} > 15$ (for $N_{Jet} > 0$)
Cut 4 Invariant mass $m_{\ell\ell}$	$m_{\ell\ell} < M_H/2 \text{ GeV (80 GeV)}$
Cut 5 Sum of p_T and \cancel{E}_T	$M_H/2 + 20(10) \text{ GeV} < p_T^{\ell_1} + p_T^{\ell_2} + \cancel{E}_T < M_H$
Cut 6 Transverse mass $m_T^{\ell\ell}$	$M_H/2 < m_T^{\ell\ell} < M_H - 10 \text{ GeV}$
Cut 7 H_T (scalar sum of p_T^{Jet})	$H_T^{Jet} < 100 \text{ GeV}$
Cut 8 Lepton opening angle $\Delta\phi_{\ell\ell}$	$\Delta\phi_{\ell\ell} < 2.0$

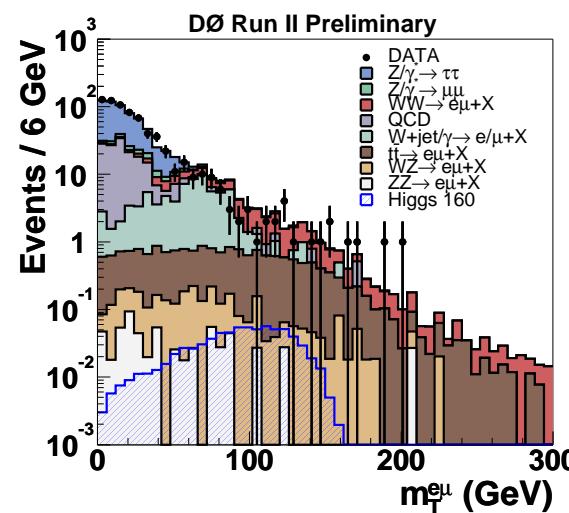
Control plots (preselection)



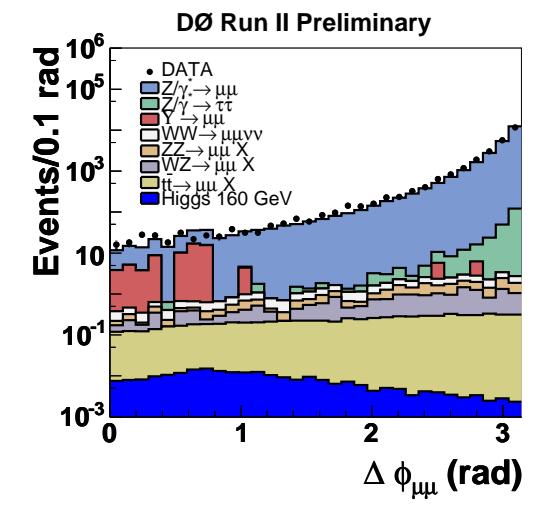
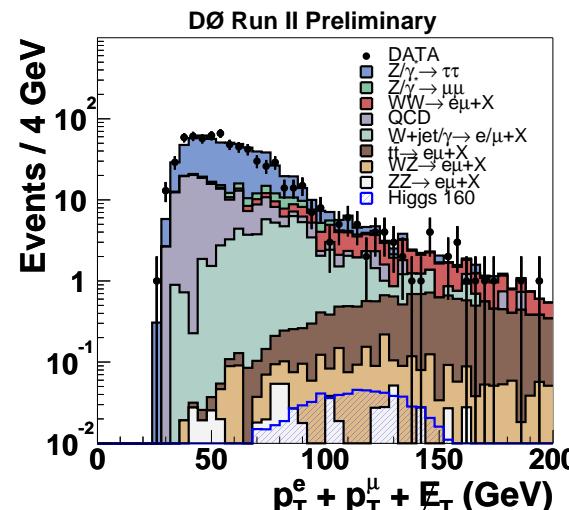
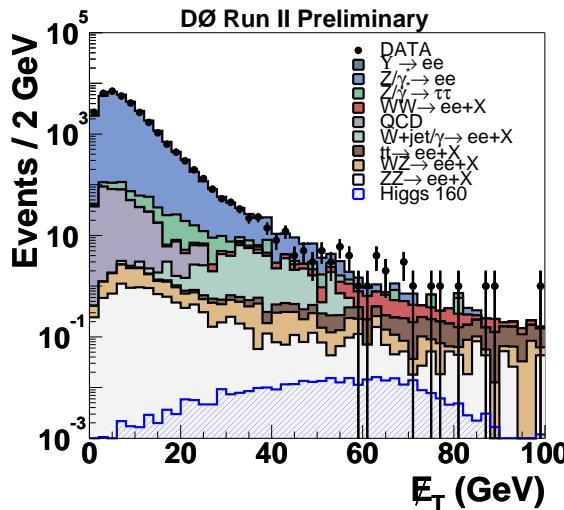
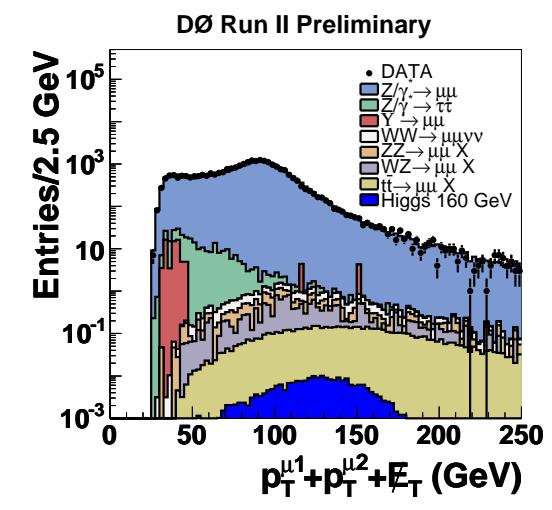
e^+e^- channel



$e^\pm\mu^\mp$ channel



$\mu^+\mu^-$ channel



Data and MC comparison (one example)



$e^\pm \mu^\mp$ channel
 $M_H = 160$ GeV

	$t\bar{t}$	ZZ	WZ	WW
1	15.9 ± 0.2	0.61 ± 0.12	2.69 ± 0.22	42.7 ± 0.5
2	14.4 ± 0.2	0.31 ± 0.09	2.03 ± 0.19	32.7 ± 0.5
3	2.59 ± 0.10	0.13 ± 0.06	1.44 ± 0.16	27.1 ± 0.4
4	1.24 ± 0.07	0.07 ± 0.04	0.54 ± 0.10	16.0 ± 0.3
5	0.60 ± 0.05	0.05 ± 0.03	0.27 ± 0.07	8.03 ± 0.23
6	0.47 ± 0.04	0.03 ± 0.03	0.23 ± 0.06	5.90 ± 0.20
7	0.27 ± 0.03	0.03 ± 0.03	0.23 ± 0.06	5.89 ± 0.20
8	0.25 ± 0.03	0.0 ± 0.0	0.20 ± 0.06	5.51 ± 0.19

	$Z/\gamma^* \rightarrow \mu\mu$	$Z/\gamma^* \rightarrow \tau\tau$	$W + jet/\gamma$	QCD	Sum	Data
1	26.5 ± 0.6	409 ± 10	66.3 ± 3.8	124 ± 6	$688 \pm 13 \pm 45$	691
2	7.31 ± 0.28	65.6 ± 4.0	49.0 ± 3.2	23.1 ± 2.5	$195 \pm 6 \pm 13$	174
3	4.75 ± 0.24	26.1 ± 2.4	25.8 ± 2.4	9.84 ± 1.62	$97.8 \pm 3.8 \pm 6.4$	90
4	3.82 ± 0.24	25.4 ± 2.4	22.0 ± 2.2	5.58 ± 1.22	$74.6 \pm 3.6 \pm 4.9$	71
5	0.50 ± 0.05	1.31 ± 0.38	2.54 ± 0.73	0.53 ± 0.38	$13.8 \pm 0.9 \pm 0.9$	12
6	0.08 ± 0.02	0.10 ± 0.07	1.09 ± 0.54	0.0 ± 0.0	$7.89 \pm 0.59 \pm 0.51$	7
7	0.08 ± 0.02	0.10 ± 0.07	1.09 ± 0.54	0.0 ± 0.0	$7.69 \pm 0.59 \pm 0.50$	7
8	0.0 ± 0.0	0.0 ± 0.0	0.87 ± 0.50	0.0 ± 0.0	$6.83 \pm 0.54 \pm 0.44$	5

- Good agreement between data and Monte Carlo
- Similar for all channels and all different Higgs masses

Overview of data and MC comparison



M _H (GeV)	100	120	140	160	180	200
<i>e⁺e⁻ channel</i>						
MC	11.1±2.0	12.1±2.1	7.3±1.1	6.1±0.9	3.7±0.4	2.9±0.3
Data	11	9	10	8	6	3
<i>e[±]μ[∓] channel</i>						
MC	10.8±1.5	9.2±1.1	7.6±0.8	6.8±0.7	6.0±0.7	5.2±0.6
Data	12	5	4	5	5	3
<i>μ⁺μ⁻ channel</i>						
MC	8.0±1.2	8.8±1.2	6.8±0.9	6.8±0.9	10.2±1.7	13.1±2.5
Data	4	7	6	6	8	8

- Dominant backgrounds
 - ▲ $W + jet/\gamma$ (e^+e^- , $e^\pm\mu^\mp$ channels, small Higgs masses)
 - ▲ WW (e^+e^- , $e^\pm\mu^\mp$ channels, high Higgs masses)
 - ▲ $Z/\gamma^* \rightarrow \mu\mu$ ($\mu^+\mu^-$ channel)



Signal efficiencies



M _H (GeV)	100	120	140	160	180	200
<i>e⁺e⁻ channel</i>						
Presel	1.86±0.06	3.03±0.07	3.77±0.09	4.23±0.09	4.74±0.09	4.81±0.08
Final	0.56±0.03	1.18±0.04	1.55±0.06	2.14±0.06	2.12±0.06	1.57±0.05
<i>e[±]μ[∓] channel</i>						
Presel	3.47±0.08	5.96±0.10	8.10±0.13	8.99±0.14	9.90±0.14	10.61±0.13
Final	1.02±0.04	2.04±0.06	2.88±0.08	3.92±0.09	3.91±0.09	3.19±0.07
<i>μ⁺μ⁻ channel</i>						
Presel	1.60±0.06	2.76±0.07	3.67±0.09	4.06±0.09	4.14±0.09	4.60±0.09
Final	0.44±0.03	1.02±0.04	1.34±0.05	2.00±0.06	1.68±0.06	1.53±0.05

- Best efficiencies in the mass range of 160–180 GeV (as expected)
- Dominant efficiency loss: cut on sum of p_T and \cancel{E}_T
 - ▲ Needed to reject major $W + jet/\gamma$ background
- 0.7 Higgs events expected for $M_H = 160$ GeV (approximately 6 events in 4th generation model)



Systematic studies



- Various sources of systematic uncertainties
 - ▲ Jet energy scale
 - ▲ Electron and muon ID efficiencies, trigger efficiencies
 - ▲ Electron and muon resolution
- Signal specific uncertainties
 - ▲ PDF variation
- Background specific uncertainties
 - ▲ Background cross sections
- All parameters are varied within $\pm 1\sigma$ of their experimental/theoretical uncertainties



Systematic studies



M _H (GeV)	100	120	140	160	180	200
<i>e⁺e⁻ channel</i>						
Signal	±8.3	±8.3	±6.4	±6.6	±6.9	±6.8
Background	+5.2 -4.9	+4.7 -4.4	+4.9 -5.2	+5.5 -5.6	+7.3 -7.9	+7.0 -8.5
<i>e[±]μ[∓] channel</i>						
Signal	±6.4	±6.7	±6.9	±6.7	±6.6	±6.1
Background	+5.9 -5.3	+10.4 -7.5	+10.1 -6.9	+7.9 -7.4	+8.1 -8.0	+8.7 -8.2
<i>μ⁺μ⁻ channel</i>						
Signal	±7.8	±7.3	±7.2	±7.1	±7.3	±6.9
Background	+4.8 -5.4	+5.8 -4.8	+3.7 -7.5	+3.7 -7.5	+10.3 -10.4	+13.7 -11.8

- Dominant errors: JES (small M_H), WW, Z/γ cross section (high M_H), PDF (signal)

Limit calculation

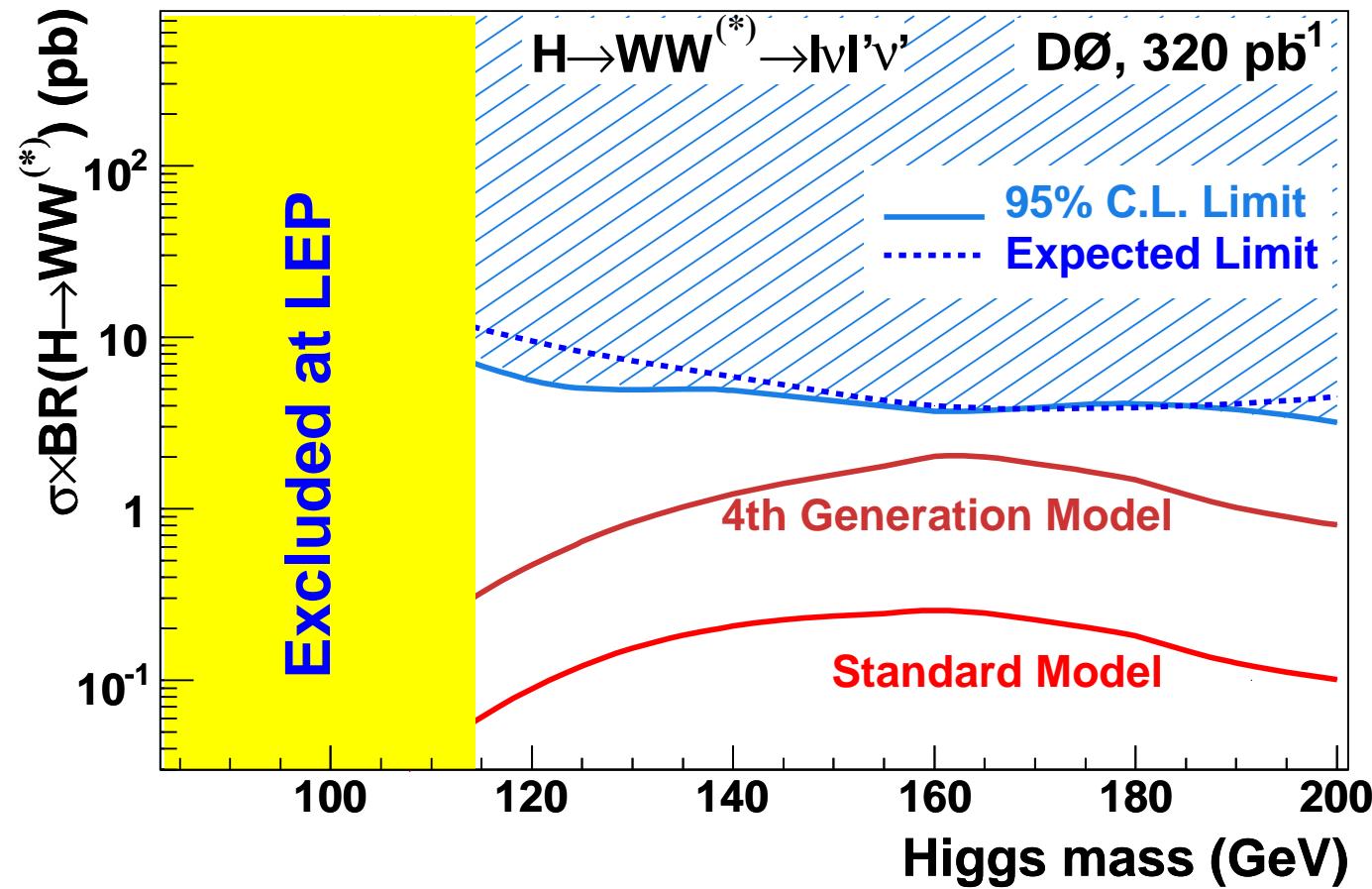


- Good agreement between data and Standard Model prediction
- No hints for a Higgs signal have been found
⇒ Set limits on the Higgs production cross section
- Use Modified Frequentist Approach (standard recipe)

Upper limit on the cross section times branching ratio $\sigma \times BR(H \rightarrow WW^{(*)})$

M _H (GeV)	100	120	140	160	180	200
Expected limits (pb)	20.3	9.5	5.9	4.0	3.9	4.5
Observed limits (pb)	18.5	5.6	4.9	3.7	4.1	3.2
CL _B	0.41	0.06	0.30	0.41	0.59	0.16





- Approximately factor of 15 missing for the Standard Model Higgs boson
- No sensitivity for alternative models yet (factor 2)

Summary



- Performed search for $H \rightarrow WW^{(*)}$ decays in leptonic decay channels
- Good agreement between data and Monte Carlo is found
 - ⇒ Set limits on the production cross section
 - ⇒ Limits between 3.7 and 18.5 pb on $\sigma \times BR(H \rightarrow WW^{(*)})$
- No sensitivity for Standard Model Higgs or alternative models yet
- Thanks to everyone who contributed to this analysis, in particular
 - ▲ The Higgs group convenors: Avto, Gregorio, and Suyong
 - ▲ Editorial Board 005: Ron, Linda, Ursula, Herb, Andrew, Vlada

